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Comparison of Four Precipitation Based Meteorological Drought Indices in Yesilirmak Basin, Turkey

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Abstract

Drought, which is often defined as not enough precipitation, does not mean a simple lack of precipitation. This condition, which occurs when humidity is less than the average value for many years, is caused by a disrupted balance between precipitation and evaporation in a region. It is very difficult to predict the start and the end time of drought. In the present study, the drought conditions of the stations selected from Yesilirmak Basin between 1970 and 2014 were determined by using Z-Score Index (ZSI), China-Z Index (CZI), Modified China-Z Index (MCZI), and Standard Precipitation Index (SPI), and the compliance of these indices to the SPI was investigated. It was determined that these indices gave parallel results to each other, and SPI detected drought earlier than other indices.

Keywords: Drought indices; Drought monitoring; SPI; ZSI; CZI; MCZI

1. Introduction

Drought, which is the most dangerous among natural disasters, has not yet been defined in full in the world literature. The effects of drought are felt increasingly all over the world. In general, human beings become aware of drought when there is water shortage (Hejazizadeh and Javizadeh 2011). It is very difficult to predict the start and end time of droughts because it is a disaster occurring insidiously showing effects gradually and continuing for a long time. Although earthly and regional climate characteristics play very important roles in the emergence of drought, the climate is not the only reason. The reasons for the emergence of droughts are not always the same factor in every basin. Also, the same lack of precipitation causes different perceptions at different times of the year in different areas. The causes of droughts are not yet clearly defined. Drought, which is often defined as not enough precipitation, is not a mere lack of precipitation. Drought occurs if humidity is less than the average value for many years due to a disrupted balance between precipitation and evaporation in an area (Downer et al. 1967).

It has been observed in recent years that researchers have used various drought indices with greater emphasis on drought studies with global warming (Lloyd-Hughes and Saunders 2002; Sirdas and Sen 2003; Deo and Sahin 2015; Yue et al., 2015; Oguzturk and Yildiz 2016; Osuch et al. 2016; Ionita et al. 2016; Wang et al. 2017; Gumus and Algin 2017; Yacoub and Tayfur 2017; Ramkar and Yadav 2018; Myronidis et al. 2018; Bushra et al. 2019; Garcia-Leon et al. 2019; Payab and Turker 2019; Pathak and Dodamani 2019; Yenigun and Ibrahim 2019; Kumanlioglu 2020; Vergni et al. 2021). Morid et al. (2006) conducted a study in Tehran and compared seven different drought indices (Standard Precipitation Index (SPI), Percent of Normal (PN), Deciles Index (DI), Z-Score Index (ZSI), China-Z Index (CZI), Modified China-Z Index (MCZI), and Effective Drought Index (EDI)). A total of 32 years' meteorological measurement data of the city were used. As a result of the study, it was concluded that DI reacted rapidly to precipitation events in certain years, but exhibited temporal and field inconsistencies, and SPI and EDI were good at detecting the start of drought showing temporal and field consistency, but EDI produced more sensitive results than SPI. In their study, Dogan et al. (2012) compared six different drought indices in Konya Closed Basin. They used the drought indices of PN, Rainfall decile-based Drought Index (RDDI), ZSI, CZI, SPI and EDI. They also used 18 different time periods for all drought indices except for EDI for 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 18, 24, 30, 36 and 48 months. According to EDI results between January 1972 and December 2009, a total of 196 drought events were detected in the basin. Soleimani et al. (2013) conducted a study to determine the start of drought in Talegani city,

which is a semi-arid area in Iran, and analyzed SPI, RDDI and CZI relatively to each other. They found that SPI yielded the best results after using 41 years' average precipitation data from eight different precipitation stations.

In this study, the purpose was to calculate, compare, and evaluate four meteorological drought indices (ZSI, CZI, MCZI, SPI) for various time periods to identify droughts in Yesilirmak Basin, and also to examine the relations between drought indices and time periods. The total monthly precipitation values of Amasya, Çorum, Samsun and Tokat meteorological observation stations located in Yesilirmak Basin were used. When longer records are used to calculate drought indices, more reliable results can be obtained (Wu et al. 2001). For this reason, applications were made for a 45-year period between 1970 and 2014, which was the longest data range for the specified meteorology stations.

2. Study area

The Yesilirmak Basin covers the area in the northern part of Anatolia, which discharges its waters into the Black Sea with Yesilirmak. The Basin Area is surrounded by Canik, Giresun, Gümüşhane, Pulur, Cimen, Kizildag, Kose, Tekeli, Yildiz, Çamlıbel, Akdaglar, Karababa, İnegöl, and Kunduz Mountain peaks with water separation line, and the Black Sea; and constitutes approximately 38732.8 km². The precipitation area of Yesilirmak Basin is 36129 km², with an average annual precipitation of 646 mm (TUBITAK 2010). The localization of Amasya, Çorum, Samsun, and Tokat meteorological stations used in the study in the basin are given in Figure 1; and positional characteristics are given in Table 1.

Table 1 Positional characteristics of selected meteorological stations

Station Name	Station Code	Elevation (m)	Latitude (N)	Longitude (E)
Amasya	17085	409	40.6668	35.8353
Çorum	17084	776	40.5461	34.9362
Samsun	17030	4	41.3435	36.2553
Tokat	17086	611	40.3312	36.5577

INSERT FIGURE 1

Fig. 1 Distribution of meteorological stations in Yesilirmak Basin (TUBITAK 2010)

3. Drought indices

3.1. Standard precipitation index

McKee et al. (1993) developed SPI to identify and monitor regional droughts. In fact, SPI ensures the standardized conversion of the observed precipitation probability; and can be calculated for desired time periods (1, 3, 6, 9, 12, 24, and 48 months). Short-term time periods (weekly and monthly) are important for agricultural water requirements and water potentials, and long-term time periods such as years (12, 24, 36 months) are important for water supply, water resources management, and groundwater studies (Mishra and Singh 2011). SPI can be used according to normal, log-normal, and gamma distribution of precipitation (Yacoub and Tayfur 2017). However, it was reported that climatic precipitation series match gamma distribution better (Thom 1985; Mishra and Singh 2010; Yacoub and Tayfur 2017). The probability density function of the gamma distribution is given in Eq. (1); and Gamma Function is given in Eq. (2).

$$g(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}}; x, \alpha, \beta > 0 \quad (1)$$

$$\Gamma(\alpha) = \int_0^\infty x^{\alpha-1} e^{-x} dx \quad (2)$$

In Eqs. (1) and (2), x refers to the amount of precipitation, and $\Gamma(\alpha)$ is the Gamma Function. SPI requires that a Gamma probability density function is adapted to frequency distribution given with precipitation totals for a station. The shape (α) and scale (β) parameters of the gamma probability density function are predicted for each station and time period in question. The maximum probability solutions given by Thom (1958) are used in predicting the α and β (Bacanli et al. 2009; Bacanli and Kargi 2019). α and β are obtained as shown in Eq. (3).

$$\alpha = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}} \right); \beta = \frac{\bar{x}}{\alpha}; A = \ln(\bar{x}) - \sum \frac{\ln(x)}{n} \quad (3)$$

In Eq. (3), n refers to the number of observations, and the resulting parameters are used in forming the probability function given in equation (4) (Bacanli 2017).

$$G(x) = \int_0^x g(x) dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-\frac{x}{\beta}} dx. \quad (4)$$

When $t=x/\beta$, the Gamma Function is in the form of Eq. (5) (Yacoub and Tayfur 2020).

$$G(x) = \frac{1}{\Gamma(\alpha)} \int_0^x t^{\alpha-1} e^{-t} dt. \quad (5)$$

The gamma distribution is non-defined for zero values of x ; however, since the precipitation series may contain zero values, the cumulative probability distribution for zero precipitation and precipitations other than zero is identified as equation (6) (Lloyd-Hughes and Saunders 2002).

$$H(x) = q + (1 - q)G(x). \quad (6)$$

In equation (6), "q" is the probability of zero. If "m" is the number of zeros in the precipitation time series, it can be predicted as $q=m/n$. The probability function $H(x)$ is converted into SPI that has an average of zero and a variance of "1" with a standard normal random value. The SPI value according to $H(x)$ value obtained in this way is calculated as in Eqs. (7) and (8) (Abramowitz and Stegun 1965).

$$0 < H(x) < 0.5, SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \quad (7)$$

$$0.5 < H(x) < 1.0, SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \quad (8)$$

$c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$ and $d_3 = 0.001308$ are constant throughout the equation (McKee et al. 1995).

The dry and humid periods are represented in the same way in the selected time period as a result of the normalization of SPI values. The month in which the index value falls below -1 is defined as the start of the drought, and the time period in which the index continues below -1 is defined as the "dry period" in drought evaluations (McKee et al. 1995; Mishra and Singh 2011). According to the index results, drought categories are given in Table 2.

3.2. Z-score index

Raw precipitation data are used in ZSI method, which is a unidimensional drought index. As seen in Eq. (9), it is obtained by dividing the difference of the average into the standard deviation without converting the precipitation to normal distribution within the specified time period (Wu et al. 2001). ZSI has standard deviation and standard average, in other words, the standard average (0) and standard deviations of ZSI values are equal to (1), and the values above the average are positive, and those below are negative.

$$ZSI = \frac{x_i - \bar{x}}{\sigma} \quad (9)$$

In Eq. (9), x_i refers to the precipitation values in the time period, $\bar{x}$ refers to the average precipitation data, and σ refers to the Standard Deviation. The drought classification according to ZSI is given in Table 2.

3.3. China-Z index

It is a drought index assuming that the CZI precipitation data fits to the Pearson Type III Distribution. It has been used by China National Climate Center since 1995 to monitor drought conditions throughout the country; and is calculated as shown in Eq. (10) (Morid et al. 2006; Dogan et al. 2012; Jain et al. 2015; Payab and Turker 2019).

$$CZI = \frac{6}{C_s} \left(\frac{C_s}{2} ZSI + 1 \right)^{1/3} - \frac{6}{C_s} + \frac{C_s}{6}; C_s = \frac{\sum_{j=1}^n (x_j - \bar{x})^3}{n \sigma^3} \quad (10)$$

Eq. (10), x_j refers to the amount of precipitation converted into normal distribution in the time period, n refers to the total number of time periods, ZSI refers to the results of the Z Score Index, and C_s refers to the skewness coefficient of precipitation data. The drought classification according to CZI value is given in Table 2.

3.4. Modified China-Z index

The calculation of MCZI is similar to the calculation of CZI, only the median value is used instead of the average in Eq. (10) (Wu et al. 2001). The acquisition of the index is given in Eq. (11) (Morid et al. 2006).

$$MCZI = \frac{6}{C_s} \left(\frac{C_s}{2} \varphi_j + 1 \right)^{1/3} - \frac{6}{C_s} + \frac{C_s}{6}; C_s = \frac{\sum_{j=1}^n (x_j - \bar{x})^3}{n \sigma^3}; \varphi_j = \frac{x_j - Me}{\sigma} \quad (11)$$

In Eq. (11), φ_j is the standard variable, and Me refers to the median value of precipitation. The drought classification according to MCZI value is given in Table 2.

Table 2 Classification of drought conditions according to the SPI, ZSI and CZI/MCZI (Morid et al. 2006; McKee et al. 1995; Kutiel et al. 1996; Jain et al. 2015)

Category	SPI	ZSI	CZI/MCZI
Normal	-0.99 to 0.99	-0.99 to 0.99	-0.99 to 0.99
Moderately dry	-1.0 to -1.49	-1.0 to -1.49	-1.0 to -1.49
Severe dry	-1.5 to -1.99	-1.5 to -1.99	-1.5 to -1.99
Extreme dry	≤ -2	≤ -2	≤ -2

4. Results and discussion

In the scope of the study, SPI, ZSI, CZI and MCZI were applied in three different time scales (3-months, 12-months, 24-months) for 4 meteorology stations selected in the Yesilirmak Basin, and the progression of the indices on the time axis are given in Figures 2-5. In the evaluations, SPI was identified as the reference index since it showed the beginning of droughts earlier, was reliable, only required precipitation data, and yielded better results (Morid et al. 2006; Dogan et al. 2012; Mishra and Singh 2011; Yacoub and Tayfur 2017).

INSERT FIGURE 2

Fig. 2 Drought indices values of Amasya for 3-, 12- and 24-months periods

INSERT FIGURE 3

Fig. 3 Drought indices values of Corum for 3-, 12- and 24-months periods

INSERT FIGURE 4

Fig. 4 Drought indices values of Samsun for 3-, 12- and 24-months periods

INSERT FIGURE 5

Fig. 5 Drought indices values of Tokat for 3-, 12- and 24-months periods

The Figures 2-5 in which the temporal change of the 4 drought indices were given were evaluated, and Tables 3-6 were prepared. The most severe and the longest durations of the droughts determined by the indices for each station are determined in these Tables, and the start and end dates of the droughts in question are given.

1 **Table 3** The longest dry periods and the date of most extreme dry for Amasya Station

Indices	The longest dry period	Duration (Month)	Value of the most extreme drought	Date
SPI-3	7/2013-2/2014	8	-4.54	8/2003
ZSI-3			-2.00	
CZI-3	8/2000-1/2001	6	-2.18	
MCZI-3			-2.18	
SPI-12	7/1973-2/1975	20	-3.17	6/2001
ZSI-12			-2.45	
CZI-12	12/2013-10/2014	11	-2.79	
MCZI-12	2/2001-11/2001	10	-2.74	
SPI-24	9/1973-2/1978	54	-2.62	11/1974
ZSI-24			-2.06	
CZI-24	11/1991-11/1992	13	-3.54	
MCZI-24	5/1975-12/1975	8	-3.10	

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1 **Table 4** The longest dry periods and the date of most extreme dry for Corum Station

Indices	The longest dry period	Duration (Month)	Value of the most extreme drought	Date
SPI-3	6/2013-2/2014	9	-3.54	9/1991
ZSI-3			-1.92	
CZI-3	7/2013-2/2014	8	-2.37	
MCZI-3			-2.27	
SPI-12	7/2013-9/2014	15	-3.97	2/2014
ZSI-12	9/1973-7/1974		-3.04	
CZI-12	11/1984-9/1985	11	-3.00	
MCZI-12	5/1994-3/1995		-3.01	
	10/2013-8/2014			
SPI-24	6/1994-9/1996	28	-2.75	7/2014
ZSI-24			-2.28	
CZI-24	6/1994-3/1996	22	-2.52	
MCZI-24			-2.47	

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1 **Table 5** The longest dry periods and the date of most extreme dry for Samsun Station

Indices	The longest dry period	Duration (Month)	Value of the most extreme drought	Date
SPI-3	4/1976-10/1976	7	-3.58	
	3/1985-9/1985			
	8/1974-11/1974			
ZSI-3	7/1981-10/1981		-2.08	
	6/1994-9/1994			
	1/2014-4/2014			
CZI-3	8/1974-11/1974	4	-3.05	8/2001
	7/1981-10/1981			
	6/1989-9/1989			
	6/1994-9/1994			
	7/2001-10/2001			
MCZI-3	1/2014-4/2014		-2.76	
	8/1974-11/1974			
	7/1981-10/1981			
SPI-12	3/1981-5/1983	27	-3.07	10/1981
ZSI-12			-2.44	
CZI-12	4/1981-7/1982	16	-2.59	
MCZI-12			-2.56	
SPI-24	12/1980-3/1984	40	-2.99	6/1982
ZSI-24			-2.45	
CZI-24	7/1981-9/1983	27	-2.87	
MCZI-24	7/1981-6/1983	24	-2.65	

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Table 6 The longest dry periods and the date of most extreme dry for Tokat Station

Indices	The longest dry period	Duration (Month)	Value of the most extreme drought	Date
	7/1974-11/1974			
SPI-3	8/1975-12/1975		-3.97	
	8/1982-12/1982			
	8/1984-12/1984	5		9/1994
ZSI-3			-1.96	
CZI-3	8/84-12/84		-2.13	
MCZI-3			-2.11	
SPI-12	6/1973-5/1975	24	-3.13	
ZSI-12			-2.49	
CZI-12	6/1973-3/1975	22	-2.40	6/1974
MCZI-12			-2.44	
SPI-24	2/1973-8/1977	55	-3.76	
ZSI-24			-3.11	
CZI-24	4/1973-9/1976	42	-3.04	10/1974
MCZI-24			-3.01	

As seen in Figures 2-5 and Tables 3-6, according to the results of 3-month indices for Amasya Station, the driest month was August 2003, June 2001 for 12-month indices, and November 1974 for 24-month indices (Table 3). For Corum, September 1991, February 2014, and July 2014 were the driest months for 3, 12, and 24-months indices, respectively (Table 4). For Samsun, August 2001, October 1981, and June 1982 were found to be the driest months according to the results of 3, 12, and 24-months indices, respectively (Table 5). For Tokat Station, the driest month was September 1994 according to 3-months indices, June 1974 for 12-months indices, and October 1974 for 24-months indices (Table 6). The driest dates indicated by different drought indices in selected time periods for each station were parallel.

As seen in Tables 3-6, as the time periods examined in the indices increased, the duration of droughts increased. Also, among all indices, SPI results yielded the longest droughts in all time periods. SPI results recorded

the longest droughts in all time periods. The longest dry periods were 8 months, 9 months, 7 months, and 5 months, respectively according to SPI-3 results for Amasya, Çorum, Samsun and Tokat; 20 months, 15 months, 27 months, and 24 months for SPI-12; and 24 months, 28 months, 40 months, and 55 months for SPI-24.

It was seen that SPI determined drought earlier than other indices used. This was evident in Samsun and Tokat for 12-months index values in all stations for 24-months index values. It was seen that the fact that the SPI determined the drought earlier was a remarkable feature of the index.

The correlation matrix and scatter diagrams of the stations were also prepared to examine the agreement better between the indices. The correlation (R) matrix is given in Tables 7-9, and the scatter diagrams are given in Figures 6-9.

Table 7 Correlation matrix of drought indices (3-months scale)

Station	Indices	ZSI-3	CZI-3	MCZI-3
Amasya	SPI-3	0.9652	0.9766	0.9766
Çorum		0.9635	0.9892	0.9889
Samsun		0.9764	0.9989	0.9985
Tokat		0.9585	0.9721	0.9721

Table 8 Correlation matrix of drought indices (12-months scale)

Station	Indices	ZSI-12	CZI-12	MCZI-12
Amasya	SPI-12	0.9935	0.9990	0.9990
Çorum		0.9937	0.9931	0.9931
Samsun		0.9957	0.9983	0.9983
Tokat		0.9957	0.9935	0.9935

Table 9 Correlation matrix of drought indices (24-months scale)

Station	Indices	ZSI-24	CZI-24	MCZI-24
Amasya	SPI-24	0.9951	0.9914	0.9933
Çorum		0.9977	0.9997	0.9997
Samsun		0.9972	0.9997	0.9997
Tokat		0.9961	0.9950	0.9950

INSERT FIGURE 6

Fig. 6 Scatter diagram of Amasya

INSERT FIGURE 7

Fig. 7 Scatter diagram of Çorum

INSERT FIGURE 8

Fig. 8 Scatter diagram of Samsun

INSERT FIGURE 9

Fig. 9 Scatter diagram of Tokat

It was seen that the correlation values in Tables 7-9 ranged from 0.9585-0.9997, and the indices in scatter diagrams of the stations in Figures 6-9 were in very good agreement with each other. The highest correlation value was found in Samsun Station (0.9989) between SPI-CZI for 3-months index values, and SPI-CZI and SPI-MCZI Indices pairs for 12 and 24-months index values. For 12-months results, the correlation value of the indices for Amasya Station reached 0.9990; and 24-months index values reached the highest correlation value of 0.9997 for the specified index pairs for Çorum and Samsun Stations. When the duration of the indices increased, it was found that the correlation values also increased, and the indices were more compatible with each other.

5. Conclusion

In the present study, drought analysis was made for Yesilirmak Basin, which is one of the basins of Turkey with water potential and drought risk. The data for 4 meteorological stations selected from the basin between 1970 and 2014 were obtained from the Turkish State Meteorological Service. Four different meteorological drought indices (ZSI, CZI, MCZI and SPI), which required precipitation data were calculated in three-time scales (3-months, 12-months, and 24-months); and drought quantities (intensity, duration) were examined. Also, the relation of the indices with SPI, which was selected as the reference index, was investigated and evaluated.

As seen in time series Tables and scatter diagrams high correlation values were obtained between SPI and ZSI, CZI and MCZI with graphs compatible with each other; and as the time intervals increased, the duration of droughts also increased in all indices. Droughts with similar intensities were detected at the same time periods for the stations included in the study. The dates of the most severe droughts were determined by four droughts indices to have a different but single date for each station and each period. Although all four indices showed similar time periods as dry periods, it was found that SPI indicated dry periods earlier than ZSI, CZI and MCZI; and these periods lasted longer. In this way, it was concluded that SPI detected droughts earlier. These three indices, which were applied successfully to determine droughts in Yesilirmak Basin, are recommended to be applied in detailed drought analyses that will be made in the basin as an alternative to SPI.

Drought analyses are very important for relevant ministries in basin action plans prepared separately for each basin by public institutions such as General Directorate of State Hydraulic Works (DSI) and local governments. Drought analysis will be made more realistically to show future water potentials in terms of sustainable integrated basin management.

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Figures

Figure 1
Distribution of meteorological stations in Yesilirmak Basin (TUBITAK 2010)

Figure 2

Drought indices values of Amasya for 3-, 12- and 24-months periods

Figure 3

Drought indices values of Corum for 3-, 12- and 24-months periods

Figure 4

Drought indices values of Samsun for 3-, 12- and 24-months periods

Figure 5

Drought indices values of Tokat for 3-, 12- and 24-months periods

Figure 6

Scatter diagram of Amasya

Figure 7

Scatter diagram of Corum

Figure 8

Scatter diagram of Samsun

Figure 9

Scatter diagram of Tokat